Preprint 22-049

STATISTICAL ANALYSIS OF DIESEL PARTICULATE MATTER AND SILICA FOR UNDERGROUND STONE MINES

M. L. Harris, CDC NIOSH, Pittsburgh, PA
E. Rubenstein, CDC NIOSH, Pittsburgh, PA
K. V. Raj, CDC NIOSH, Pittsburgh, PA
V. Gangrade, CDC NIOSH, Pittsburgh, PA

ABSTRACT

Underground stone mine ventilation is characterized by large openings with low resistances. These mines primarily face three challenges: moving adequate volumes of air, controlling and directing the airflow, and planning ventilation systems that work well with production requirements. Given these challenges, this paper examines the data collected by the Mine Safety and Health Administration (MSHA) to determine the extent to which respirable crystalline silica (RCS) and diesel particulate matter (DPM) are an issue in underground stone mines. Out of 522 sampled mines, there were 108 personal samples exceeding the RCS Permissible Exposure Limit (PEL) during 2000–2020. DPM were more prevalent than RCS in these mines with 382 personal samples exceeding the DPM PEL out of the 929 mines sampled during 2002–2020. Dilution of DPM is usually the defining parameter for design of mine ventilation systems in large-opening underground stone mines. With this knowledge, focused attention can be directed to these mines so that appropriate prevention and mitigation techniques can be utilized to prevent stone miners' exposure to RCS and DPM and subsequent respiratory diseases.

INTRODUCTION

Most limestone is mined at surface mine operations. In 2020, the National Mine Association (NMA) reported that out of the 4,248 active stone mines in the United States 110 were underground mines that employed approximately 2,000 miners to produce construction aggregates and other commodities (1). During the last decade, the number of underground stone mines gradually increased from 107 in 2009 to 114 in 2018. Existing underground mines are moving towards greater depths and multiple levels which can adversely impact ventilation effectiveness and increase health and safety risks to the underground workforce.

The continuing and emerging air quality issues for large-opening mines include elevated concentrations of silica dust, diesel particulate matter (DPM), noxious gases (from diesel equipment, welding, and production blasts) which include such gases like NO, NO_2, CO, CO_2, and other fumes. Underground stone miners can be exposed to respirable dust containing crystalline silica. In June 2018, the National Academy of Sciences (NAS) published a consensus study report on the contaminant exposures in underground coal mines (2). The report stresses the health hazards posed by respirable crystalline silica (RCS). Cumulative dust exposure can lead to chronic obstructive pulmonary disease (COPD) or various forms of pneumoconiosis such as progressive massive fibrosis (PMF) and rapidly progressive pneumoconiosis (RPP). Certain occupations such as haul truck drivers, crusher operators, front-end loader operators, and rotary drill operators have a higher risk of exposure to RCS (3). This information can inform mine operations in areas where ventilation changes may assist in remediating these exposures.

The Mine Safety and Health Administration (MSHA) regulates underground metal/nonmetal (M/NM) miners' exposure to respirable dust containing quartz silica under 30 CFR 57.5001 (4). The MSHA P-2 method, an X-Ray diffraction (XRD) method, is used as a standard method for quantifying silica in M/NM mines (5). In M/NM mines, the exposure limit to respirable silica-bearing dust is also dependent upon the percentage (%) of silica if the content is greater than 1%. The exposure limit considers three forms of crystalline silica, quartz, cristobalite, and tridymite, even though the first is the most common. The exposure limit is dependent upon the amount (%) of quartz (Q), cristobalite (C), and/or tridymite (T) present in the dust (6, 7) as follows.

$$standard\ (mg/m^3) = \frac{10\ (\frac{mg}{m^3})}{Q\ [\%]+2}$$

$$standard\ (mg/m^3) = \frac{5\ (\frac{mg}{m^3})}{C\ [\%]+2}$$

$$standard\ (mg/m^3) = \frac{5\ (\frac{mg}{m^3})}{T\ [\%]+2}$$

The mass of silica in M/NM mine samples is measured via an X-ray diffraction (XRD) method (5, 6). Only respirable (dust) samples greater than 100 µg are subject to analysis for silica.

Although the reduction of all contaminants in underground mines is vital, miners' exposure to DPM has been among the most critical areas of concern. In recognition of the potential health hazards of exposure to DPM, MSHA established allowable DPM concentrations for underground M/NM mines (CFR 57.5060(b)(3)) (8). Initially the requirements were first introduced as 308_{EC} µg/m^3 (~400_{TC} µg/m^3). This value was lowered to 350_{TC} µg/m^3 in 2007 and finally established at 160_{TC} µg/m^3 in May 2008. Ensuring that miners' personal exposure to DPM is under this 160_{TC} µg/m^3 limit can dictate airflow requirements of the entire mine.

Elemental carbon (EC) is measured using thermal optical transmittance (TOT) analysis performed on personal exposure DPM samples using the NIOSH 5040 method (9). The total carbon (TC) is either calculated as being 1.3 times the EC (organic carbon, OC, is the vapor phase hydrocarbons generally comprising 23% of the total carbon) or calculated by using the EC data and mine specific TC/EC ratio established on a number of ambient samples.

Underground stone mine ventilation presents a unique set of challenges because of the large size of underground openings. The total open-space volume in a typical large-opening mine can be enormous (~100–250 million cubic feet) and air change requires many hours to complete. The lack of air change and temperature changes can often result in high DPM and dust concentrations. Due to the low ventilation pressures encountered (10), controlling and directing airflow in these operations is through momentum of the mine airflow rather than differential pressure in the mine openings. Additionally, stoppings in large-opening operations are expensive to build and difficult to maintain due to blast pressures. Ventilation system planning is also an issue in these mining operations. As the operation grows, managers typically work multiple face areas along the perimeter of the mine and, consequently, maintaining a ventilation system is complicated by using multiple booster/auxiliary fans, proper use and fan placement, main fans, and impacts of natural ventilation pressures. Other factors contributing to these issues also include low margins associated with mining aggregates, limited resources to conduct ventilation surveys and health surveillance, limited ventilation knowledge, inadequate or outdated equipment, improperly maintained equipment, limited use of advance engine technologies and exhaust aftertreatments, and MSHA's limited means to provide oversight.

Given these challenges, this paper examines the MSHA collected data to determine the extent to which RCS and DPM may be an issue in underground stone mines. With this knowledge, focused attention can be directed to these mines so that appropriate prevention and mitigation techniques can be utilized to prevent stone miners' exposure to RCS and DPM and subsequent respiratory diseases.

METHODOLOGY

The personal health samples dataset was the primary source for the information reported in this paper (11). This dataset contains the results of sampling conducted by MSHA at metal and nonmetal (stone, and sand and gravel) mines for approximately 120 different contaminants from 2000 to the present. Table 1 presents an excerpt from the dictionary for the dataset describing relevant fields.

Table 1. Excerpt from data dictionary for the personal health samples dataset.

TABLE_NAME	COLUMN_NAME	DATA_TYPE	DATA LENGTH	FIELD_DESCRIPTION
PERSONAL HEALTH SAMPLES	CONCENTRATION	VARCHAR2	7	Concentration amount of substance or agent sampled. Format is ####.##.
PERSONAL HEALTH SAMPLES	EXPOSURE_LIMIT	VARCHAR2	7	Permissible exposure limit for the contaminant being sampled. Format is ####.##.
PERSONAL HEALTH SAMPLES	C_OVER_E	VARCHAR2	5	Results obtained by dividing concentration by the exposure limit and rounded to the nearest hundredth. Format is ##.##.
PERSONAL HEALTH SAMPLES	LOCATION_CD_DESC	VARCHAR2	50	Description of the location code of the mine employee during sampling.
PERSONAL HEALTH SAMPLES	JOB_CD	VARCHAR2	3	Code denoting the occupation of the mine employee sampled.
PERSONAL HEALTH SAMPLES	ACTION_TAKEN_DESC	VARCHAR2	26	C = Cit/Ord Issued; P = Infeasible controls; T = Cit/Ord Term; D = Overexp of 551/553, 555; E = Exceeds Pel but not PEL X error factor; L = Exposure limit exceeded; H = Noise exp exceeded (not PEL); etc.

The personal health samples dataset (and thousands of other datasets on a wide range of topics) can be downloaded from www.Data.Gov. The Data.Gov website was created under the provisions of the OPEN (Open, Public, Electronic, and Necessary) Government Data Act of 2019, which stipulates that data collected by government agencies must be made available to the public in an accessible format while maintaining privacy and security.

Under 30 CFR Part 50, mine operators are required to notify MSHA about accidents promptly and to file quarterly reports describing accidents, occupational injuries, and occupational illnesses using MSHA Form 7000-1 (12). Data from Form 7000-1 are recorded in the Accident, Injury, and Illness Information (ai) dataset. Mine operators are also required to file quarterly reports on employment, mine status (full-time active, intermittent, permanently closed, etc.), and mine address using MSHA Form 7000-2. Data from Form 7000-2 are recorded in the Address/Employment Information (ae) dataset. The ai and ae datasets for all the years since 1983 can be downloaded in text format from the MSHA website. NIOSH executes code to add descriptors to the raw data and to convert it to Statistical Package for the Social Sciences (SPSS) format. The SPSS data files can also be downloaded from the MSHA website.

Mine IDs are included in the personal health samples dataset, but the commodities produced by the mines are not included. Therefore, to select stone mines, it was necessary to merge the personal health samples dataset with the Address/Employment Information (ae) dataset (which does contain a commodity variable) using mine ID as the key for merging.

The data examined spans the years 2000–2020 and all 50 states. Due to the immense size of the database, the database was filtered first to include samples with the contaminants and codes listed in Table 2.

To focus on underground stone mine samples, the data were further filtered for underground mines under the "ug_surf" column and then filtered to include the entries listed in Table 3. As such, the data include some entries that are considered "nonmetal" and not just "stone."

Table 2. List of contaminants and contaminant codes for initial sorting.

Contaminant Code	Contaminant
121	Nuisance dust, respirable, <1% Qtz
123	Nuisance dust, total, <1% Qtz
131	Unlisted Particulate, respirable, <1% Qtz
133	Unlisted Particulate, total, <1% Qtz
505	Fibers, >5 um
511	Talc, nonfibrous, <1% Qtz
521	Respirable dust, <.1 mg
523	Quartz, respirable, >1% Qtz
529	Mixed Silica
551	Total Carbon, TC
553	Total Carbon, calculated from elemental carbon.
555	Diesel Particulate Material
557	TCarbon @ 350 μg/m^3
559	TC as EC @ 350 μg/m^3
560	EC @ 160 μg/m^3
561	TC from EC @ 160 μg/m^3
562	TC @ 160 μg/m^3

Table 3. Standard Industrial Classification (SIC) column entries for sorting.

RCS	DPM
Cement	Cement
Granite (crushed and broken)	Granite (crushed and broken)
Lime	Lime
Limestone (crushed and broken)	Limestone (crushed and broken)
Limestone (dimension)	Limestone (dimension)
Marble (crushed & broken)	Marble (crushed & broken)
Marble (dimension)	Marble (dimension)
* Sand, Industrial; Ground silica/quartz	* Sand, Industrial; Ground silica/quartz
Sandstone (crushed & broken)	Sandstone (crushed & broken)
* Shale (common)	* Shale (common)
Stone, crushed & broken, NEC	Stone, crushed & broken, NEC
Stone, dimension, NEC	
* Talc, soapstone, & pyrophyllite	* Talc, soapstone, & pyrophyllite
* Nonmetal category, all others are Stone	

Further separation of the samples was performed by filtering the datasets according to the contaminant codes. Samples with the codes 121, 123, 131, 133, 505, 521, and 523 were filtered and retained as the RCS samples. Samples with the codes 551, 553, 555, 557, 559, 560, 561, and 562 were filtered and retained as the DPM samples. The data entered in the database were not corrected for spelling errors. The text narrative was not analyzed or examined. From this selection of data, the following results were obtained.

RESULTS AND DISCUSSION

There are several limitations using the MSHA personal health sample database. The database does not represent a complete cross-section of the mining industry in any given year. In underground stone mines, the current protocol and aim are to sample each mine for RCS once every three to five years and for DPM once a year (13). In the last three years, the frequency goals for sampling at active mines were increased from 20% in 2019 to 33% in 2021. Although the sampling frequency was increased, the number of compliance samples is inadequate to represent the total populations of mines, miners, and shifts worked (14). Compliance sampling may not be random, but rather the selected occupations may be based on an inspector's discretion with the focus on perceived "at risk" occupations. The sampling may be biased toward non-compliance based upon the inspectors' professional judgement. Also, termination of citations may be based upon invalidated samples or upon implementation of remediation recommendations and subsequent sampling. Subsequent sampling could contribute to some states and mines having a higher number of sampling events. However, given that the database is readily accessible and contains years' worth of data, NIOSH researchers chose to start with an initial examination of it.

RCS

According to the previously described filtering and sorting system, there were a total of 4,978 records over the 20-year period specified having contaminant codes 121, 123, 131, 133, 505, 521, or 523. During this period, 160 mines were sampled during 1,543 separate events resulting in 108 citations, 126 terminated citations, and 26 extended citations as shown in Figure 1 and Figure 2. Pennsylvania, Missouri, and Kentucky have the most mines sampled (18, 22, and 27, respectively). Consequently, these states also have the most sampling events as well.

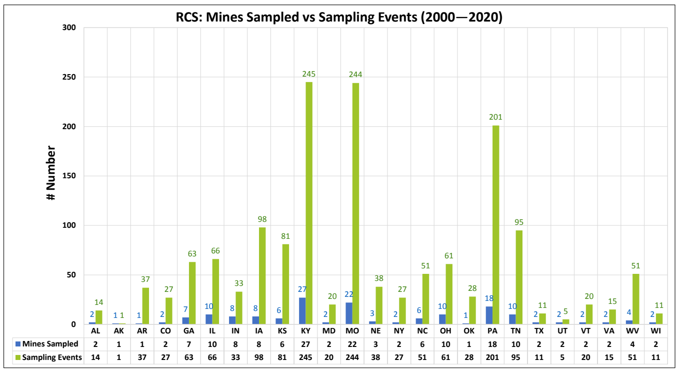

Figure 1. The number of sampled mines and the number of sampling events are shown for each state. Those states not listed have zero for both.

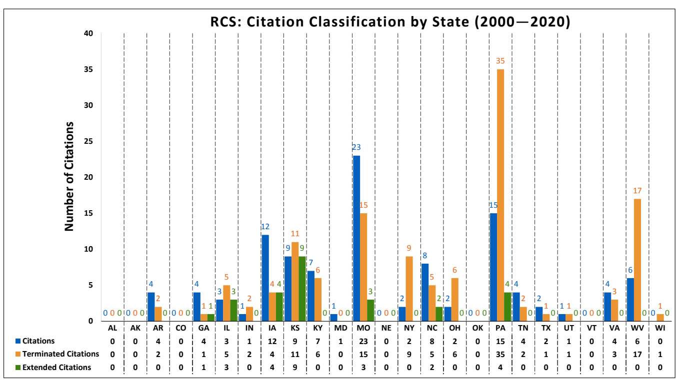

Figure 2. The number of citations, terminated citations, and extended citations for each state.

Interestingly though, the frequency of sampling events per number of mines is the highest for Arkansas (37 sampling events) and for Oklahoma (28 sampling events) where each have only one mine sampled. When compared with Pennsylvania, Missouri, and Kentucky (11.2, 11.1, and 9.1 sampling events per mine, respectively), there are other states with higher sampling event rates such as New York, Kansas, and Colorado which correspondingly have few mines sampled. This demonstrates the diversity between MSHA districts with regards to the number of active underground M/NM mines, the number of inspectors, and the frequency and ability to conduct surveys and split resources among several mines.

The number of citations tend to correspond with the frequency in sampling with a bias toward non-compliance. As seen in Figure 2, Pennsylvania and Missouri have numerous citations with Pennsylvania experiencing a large number of terminated citations. As stated previously, this may be due to the differences in how each district and field office operate due to inspector resources and the number and types of mines.

Figure 3 displays the number of mines sampled and the number of sampling events per year as well as the citations issued per year. The number of different sampled mines peaked in 2003 and 2004 at 77 mines with 126 and 124 sampling events respectively.

The crusher operator/worker has the most RCS associated citations associated with the job description–57 citations out of 260 (total of citations, extended citations, and terminated citations). Following the crusher operator/worker are the utility men and laborers/bullgang with 26 total citations each and bagging operators with 25 total citations. For these jobs, 9% to 15% of the samples resulted in citations. However, there are other less frequently sampled jobs that resulted in higher citation-per-sample percentages. These are listed in Table 4. These occupations may warrant focused attention for reduction of silica dust exposure.

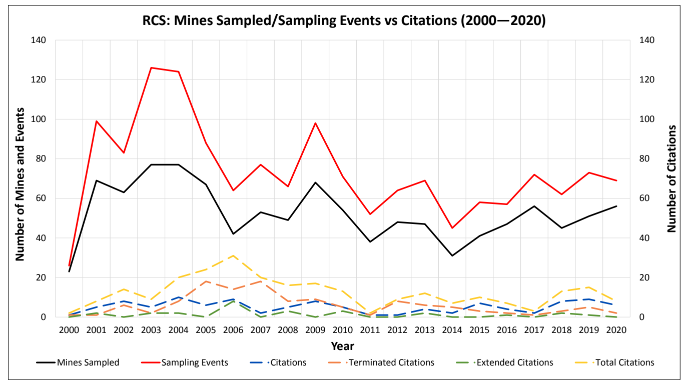

Figure 3. The number of mines sampled and the number of sampling events per year are on the left vertical axis. The number citations, terminated citations, and extended citations per year are on the right vertical axis.

Table 4. Job descriptions associated with a high percentage of resulting citations.

Job Description	Number of Sample Entries	Number of Total Citations	Percentage of Sample Entries Resulting in Citations
Flotation/Concentrator Operator	7	4	57%
Continuous Miner Helper	13	7	54%
Shotcrete/Gunite Man	4	2	50%
Continuous Miner Operator	11	5	45%
Drill Operator, Jackleg/Stoper	7	3	43%
Belt Cleaner	6	2	33%

The active underground section is sampled the most and, consequently, has the most associated citations. There are 64 citations out of 1,691 entries, a 4% ratio. The areas of the underground operation with the most citations per sampling entry are in the aboveground mill operation. As seen in Table 5, these areas all have 10% or greater of these samples resulted in citations.

Table 5. Location descriptions associated with a high percentage of resulting citations in the mill operation.

Location Description	Number of Sample Entries	Number of Total Citations	Percentage of Sample Entries Resulting in Citations
Bagging	147	21	14%
Pelletizing	7	1	14%
General	222	28	13%
Drying & Roasting	53	6	11%
Crushing	263	26	10%

DPM

Although DPM regulations were implemented in stages or phases and the current limit of 160_{TC} μg/m^3 was mandated in 2008, the whole set of data was examined, which began in 2002. This may still provide data identifying difficulties in meeting expectations. The exposure limit in the database corresponds with the appropriate mandated limit for each year. According to the previously described filtering and sorting system, there were a total of 17,252 records from 2002 to 2020 with contaminant codes 551, 553, 555, 557, 559, 560, 561, or 562. During this period, 161 mines were sampled during 2,234 separate events resulting in 382 citations, 416 terminated citations, and 80 extended citations (Figure 4). Kentucky, Pennsylvania, and Missouri have the most mines sampled (25, 23, and 18, respectively). Consequently, these states also have the most sampling events as well.

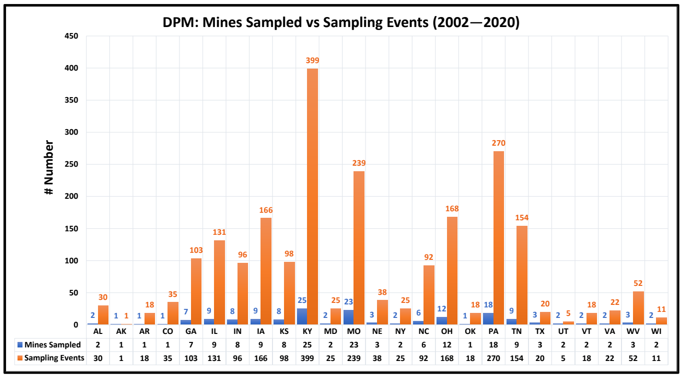

Figure 4. The number of sampled mines and the number of sampling events are shown for each state. Those states not listed have zero for both.

The frequency of sampling events per number of mines is the highest for Colorado with 35 sampling events at one mine. Like the RCS examination, when compared with Pennsylvania, Missouri, and Kentucky (15.0, 10.4, and 16.0 sampling events per mine, respectively), there are other states with higher sampling event rates such as Iowa, Arkansas, and Oklahoma which correspondingly have few mines sampled. Again, this demonstrates the differences between inspection resources and focus of the MSHA districts.

The number of citations tend to correspond with the frequency in sampling. As seen in Figure 5, Pennsylvania, Kentucky, and Missouri tend to have more citations. However, there is a high number of terminated citations in Pennsylvania and Ohio from 2002–2020. Although some citations were terminated, they are still included in the overall assessment since they represent real exposures and require resources, such as time, money, and personnel, to address or meet the exposure standards. Why some states have higher rates of terminated citations may be dependent upon how each district practices enforcement or policies. If the district is requiring subsequent sampling for termination of a citation, this district would have a higher number of events per state and mine as well.

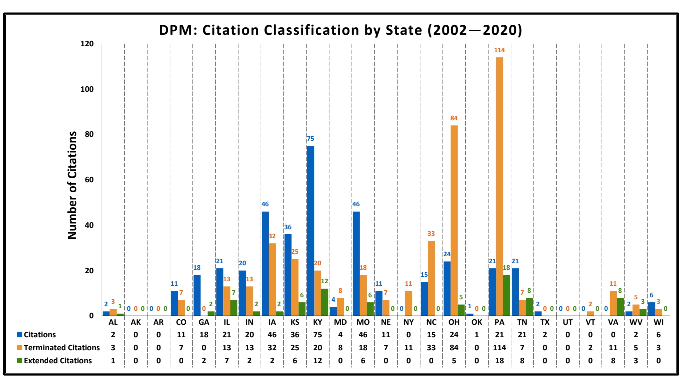

Figure 5. The number of citations, terminated citations, and extended citations for each state.

The number of citations given for the DPM standard peaked in 2008 with 114 total citations (including terminated and extended), a year after the law pertaining to DPM limits was in effect (Figure 6). In 2018, the number of sampled mines and the number of events peaked at 97 and 173, respectively. However, the total citations resulting from these events was only 6% for 2018–one of the lowest. It should be noted that after rulemaking began, the MSHA DPM sampling policy has been evolving to meet different expectations. A further review of the data from the past 5 years may be warranted to reveal other troubled areas.

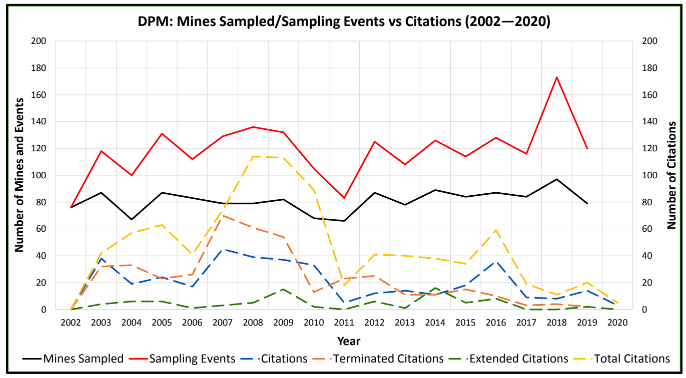

Figure 6. The number of mines sampled and the number of sampling events per year are on the left vertical axis. The number citations, terminated citations, and extended citations per year are on the right vertical axis.

The front-end loader operators were sampled the most with 3,091 entries and 101 citations for these occupations. However, blasters and their crews are associated with the most total citations, 287 total citations from 2002 to 2020 (Table 6). The occupations that cannot perform most of their work in environmental cabs will have the highest chance of overexposures. Although not sampled as often, the cleanup man has almost a quarter of his samples resulting in citations.

Table 6. Job descriptions associated with a high percentage of resulting citations.

Job Description	Number of Sample Entries	Number of Total Citations	Percentage of Sample Entries Resulting in Citations
Blaster, Powder Gang	2903	287	10%
Front-end Loader Operator	3091	101	3%
Scaling (mechanical)	2449	93	4%
Truck Driver	2704	73	3%
Drill Operator, Rotary	1108	67	6%
Drill Operator, Jumbo Perc.	993	59	6%
Roof Bolter, Rock	634	47	7%
Roof Bolter, Mounted	334	25	7%
Scaling (hand)	353	25	7%
Drill Operator, Rotary Air	597	23	4%
Cleanup Man	59	14	24%

The active underground section is sampled the most and, consequently, has the most associated citations. There are 706 citations out of 13,506 entries, a 14% ratio. Not surprising, the areas of the underground operation with the most citations are in the active underground production area. As seen in Table 7, the areas having the most samples resulting in citations are in the underground working areas during active production, development, in travel ways, or in stockpile areas. These are areas in which remediation should focus on mine design and ventilation practices.

Table 7. Location descriptions associated with a high percentage of resulting citations.

Location Description	Number of Sample Entries	Number of Total Citations	Percentage of Sample Entries Resulting in Citations
UG - Active Production	13506	706	5%
UG - Exploration & Development	695	55	8%
UG - General	668	41	6%
UG – Travel ways & Haulage ways	1,381	36	3%
UG - Load-in/out, Stockpiles	554	21	4%

CONCLUSION

Given the limitations of the MSHA database and acknowledging that the database is not representative of underground stone mine populations or shifts worked, some general observations can be made. Given that the goal is to sample for RCS every three years and for DPM every year, generally, it is not surprising that the data for underground stone mines indicate inspectors sample more frequently for DPM than for RCS. Overall, the citation per sampling rate is 5% for RCS and DPM. The majority of underground stone mines reside in Pennsylvania, Missouri, and Kentucky and correspondingly have the most associated citations. As expected, the areas indicating the most issues with DPM are located in the production areas at the active faces, in new developments, and along travel ways where the diesel-powered equipment operates. Although not the only means of mitigation or remediation, mine and ventilation design can impact and prevent DPM accumulations and exposures in these areas. However, RCS overexposures occur more frequently in the milling areas rather than in the underground production areas. Additional focus may be warranted in milling areas to reduce RCS exposures.

Since MSHA policies and resources have changed, a more in-depth examination of the data may be warranted to specifically examine the last 5 years. This could also aid in the determination of where to focus research and mine operation resources. Some new strategies being investigated to mediate DPM and RCS exposures are the use of long pillar designs, efficient and proper placement of booster fans, and harnessing the momentum of haul trucks to improve ventilation.

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH.

REFERENCES

1. NMA (2020). Mine Safety & Health Administration's Number of Coal and Non-fuel Mineral Operations in the U.S., 1979-2020. https://nma.org/wp-content/uploads/2020/09/msha_number_operations_by_sector_2020.pdf . Accessed September 2021.

2. National Academies of Sciences, Engineering, and Medicine (2018). *Monitoring and Sampling Approaches to Assess Underground Coal Mine Dust Exposures*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25111.

3. Chekan, G.J and Colinet, J.F. (2002). Silica Dust Sources in Underground Limestone Mines. In *Proceedings of the 33rd Annual Institute on Mining Health, Safety and Research*, Roanoke, Virginia, August 27–30.

4. 30 CFR 57.5001 (2021). Part 57 - safety and health standards - underground metal and nonmetal mines. https://www.ecfr.gov/current/title-30/chapter-I/subchapter-K/part-57 accessed November 2021.

5. MSHA, (2004). "Mine Safety and Health Administration, X-Ray Diffraction Determination of Quartz and Cristobalite in Respirable Mine Dust Method P2." MSHA, Arlington, VA, 2004.

6. Cauda E, Joy G, Miller A, Mischler S (2013). Analysis of the silica percent in airborne respirable mine dust samples from U.S. operations. Silica and Associated Respirable Mineral Particles, STP 1565, Martin Harper and Taekhee Lee, Eds., pp. 12–27, doi:10.1520/STP156520120210, ASTM International, West Conshohocken, PA, 2013.

7. ACGIH (1973). "Threshold Limit Values for Chemical Substances in Workroom Air." ACGIH, Cincinnati, OH, 1973.

8. CFR 57.5060(b)(3), (2020). Limit on exposure to diesel participate matter. https://www.law.cornell.edu/cfr/text/30/57.5060 accessed March 2020.

9. NIOSH (2016). Diesel particulate matter (as elemental carbon). In: NIOSH Manual of Analytical Methods (NMAM), 5th Edition, Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health https://www.cdc.gov/niosh/nmam/pdfs/NMAM_5thEd_EBook.pdf

10. Grau RH, Robertson SB, Krog RB, Chekan GJ, Mucho TP (2004). Raising the Bar of Ventilation for Large-opening Stone Mines. Proceedings of the 10th US/North American Mine Ventilation Symposium, 349–355. Retrieved from https://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/rbvlosm.pdf. Accessed March 2020.

11. Data.gov (2021). MSHA personal health samples. MSHA Personal Health Samples - CKAN (data.gov) accessed August 2021.

12. 30 CFR Part 50, 2021. Electronic Code of Federal Regulations. https://www.ecfr.gov/cgi-bin/text-idx?SID=792cb3e71f33f2d0ef5694d3160431d2&mc=true&tpl=/ecfrbrowse/Title30/30cfr50_main_02.tpl

13. MSHA, (2010). 2010 Metal/Nonmetal Health Sampling Program. https://arlweb.msha.gov/S&HINFO/2010MNMHealthSampling.pdf accessed September, 2021.

14. Meilde GB, (2021). MSHA review of the paper "Statistical analysis of diesel particulate matter and silica for underground stone mines," Gregory Meilde, October 22, 2021.